We Protect Hoosiers and Our Environment

Water

Development of Eutrophication Criteria for Lakes

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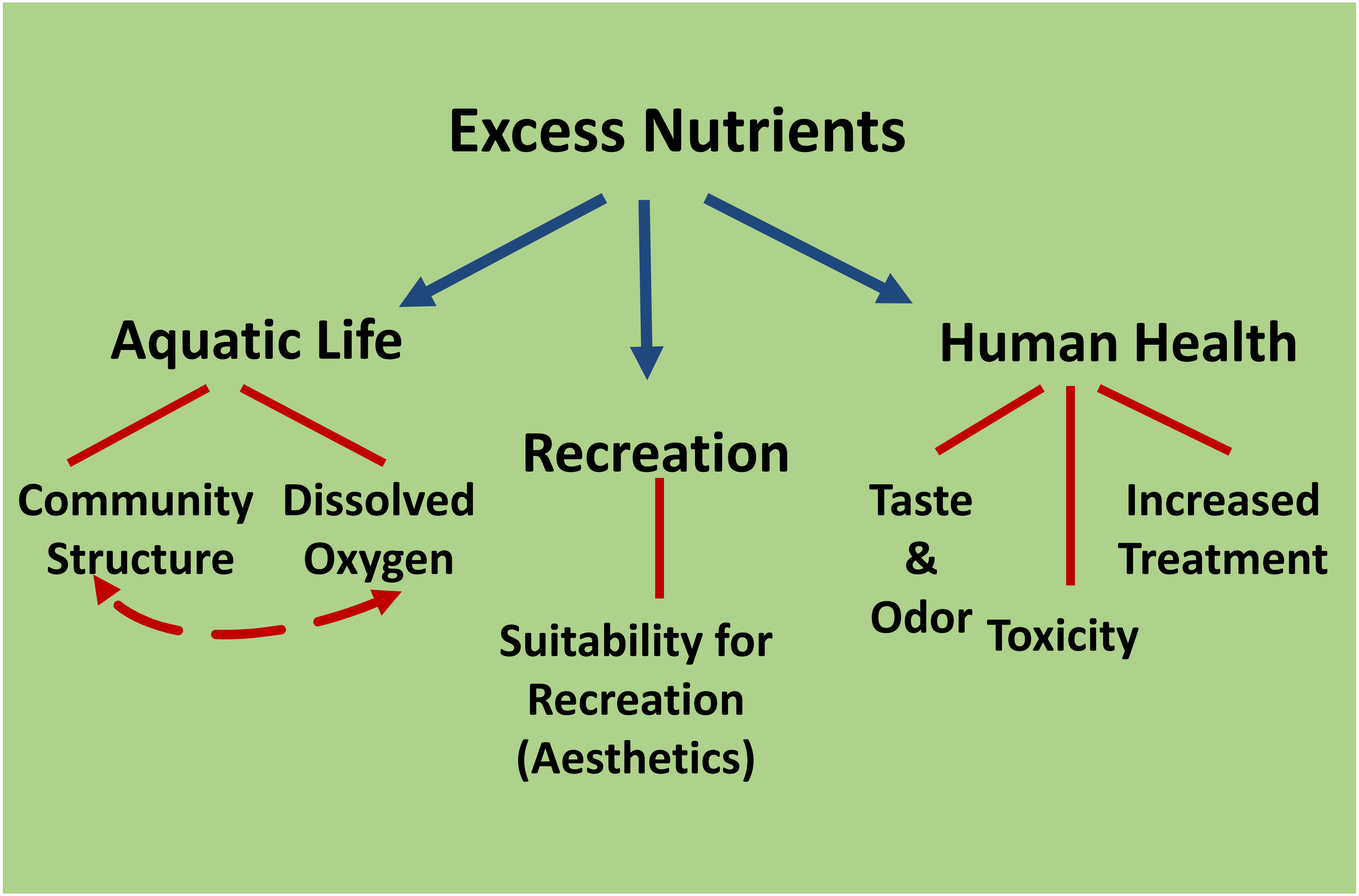
External Workgroup Meeting

December 12, 2011

Overview of Presentation

- Impacts of Excess Nutrients
- Introduction to Lakes
- Monitoring of Indiana Lakes
- Approaches to Developing Nutrient Criteria
- Data Used in Analysis
- Data Analysis Strategy
- Results
- Proposed Criteria

Impacts of Excess Nutrients



Designated Uses

- Designated uses of Indiana's surface waters:
  - Recreation in and on the water
  - Maintenance of a well-balanced, warm water aquatic community
- Criteria must provide protection of designated uses

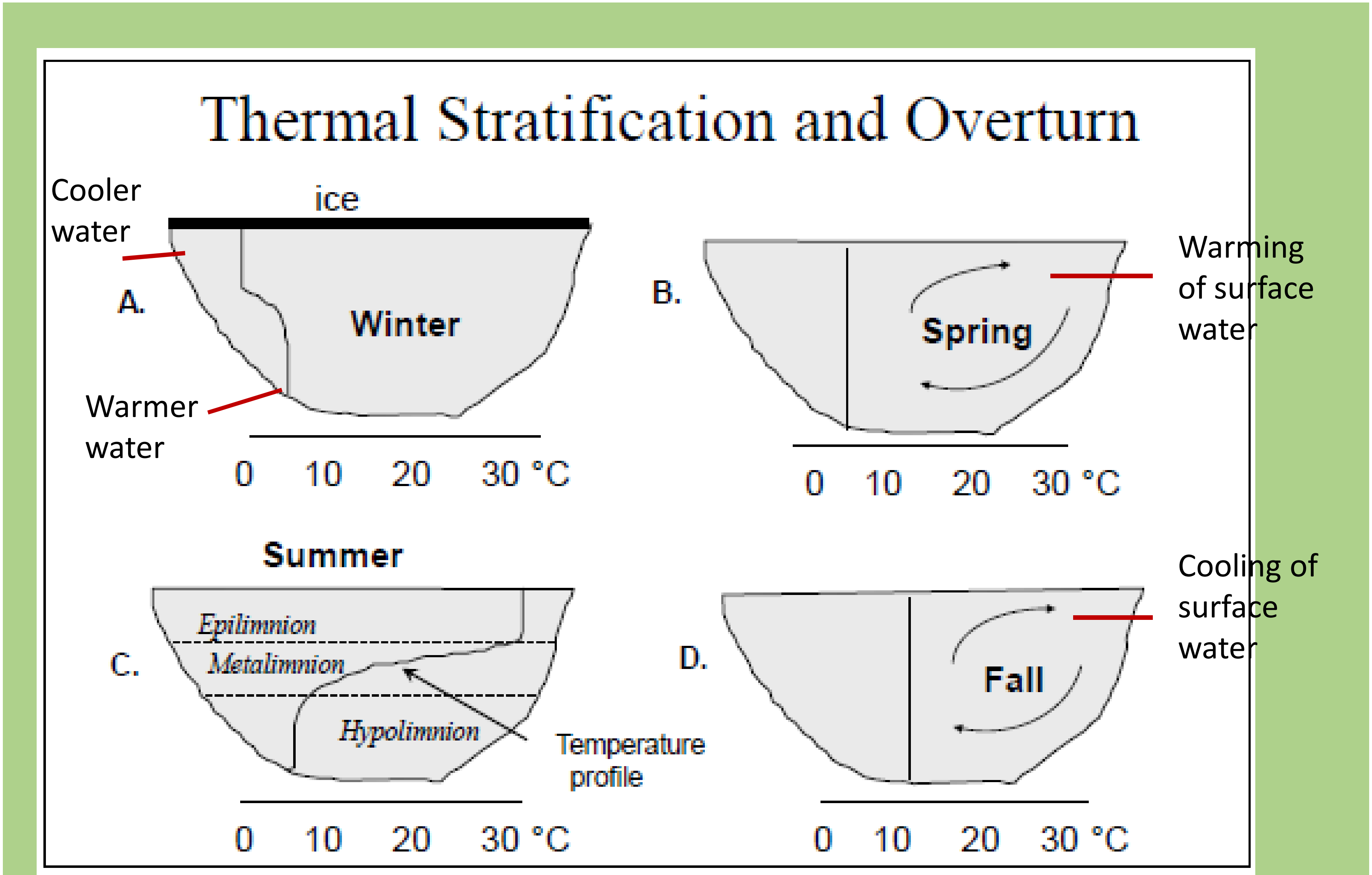
Characteristics of Lakes

- Standing bodies of water
- Bottom of watershed – receiving waters
- Physical consequences of standing water
  - Retention time – much more sensitive to nutrients, organic pollution
  - Water retained for days/months/years
  - Stratification – limited atmospheric exchange
  - Sedimentation
- Most organisms suspended in water column

Lake Dynamics

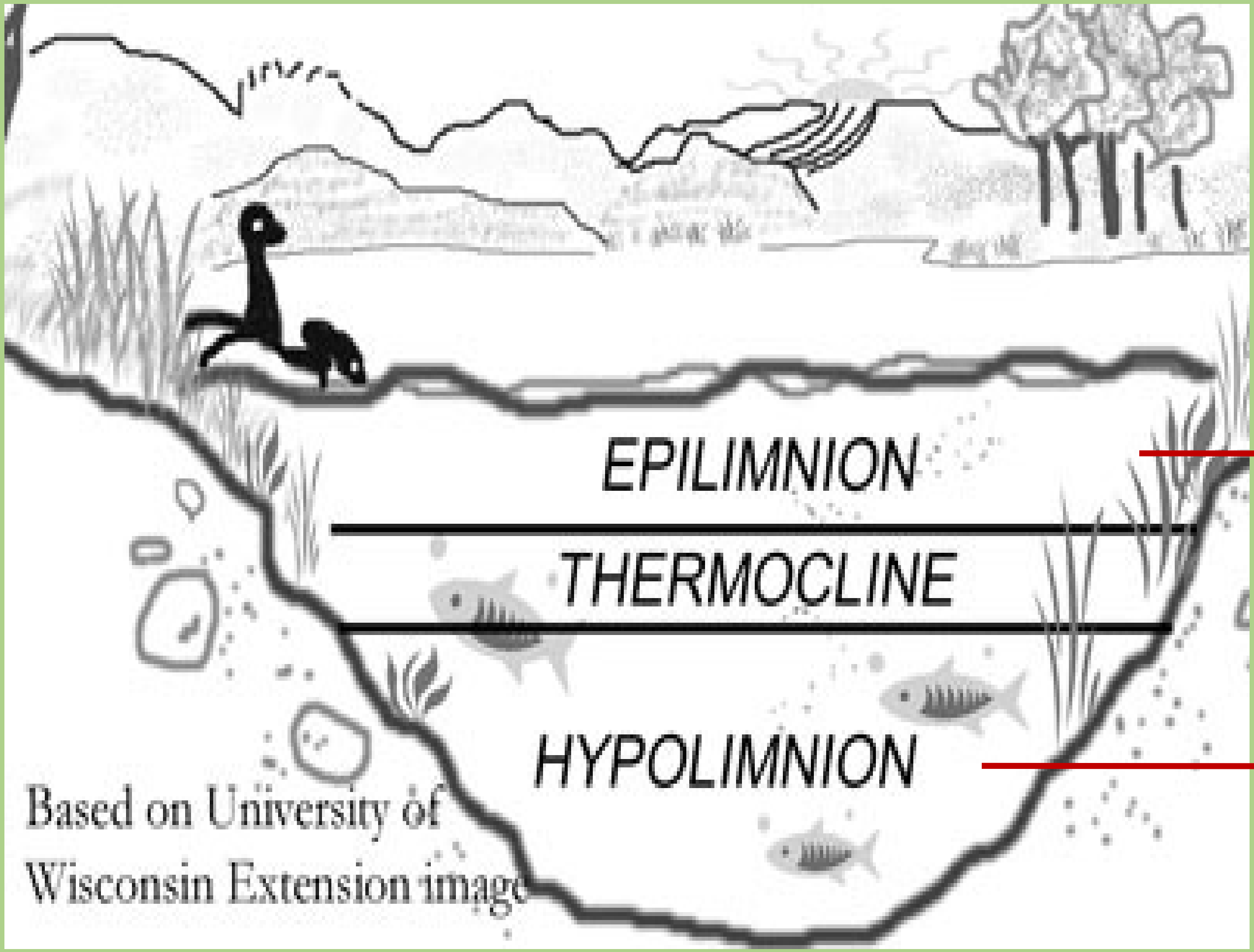
- Lakes begin life with clear, nutrient-poor waters
- Photosynthesis proceeds at limited rate
- Respiration occurs to partially decompose plant material and consume O_2 in the deep part of the lake
- Biological activity increases over a lake's "lifetime" until it gets choked with organic matter and fills-in with sediment
  - Eutrophication

How Lakes Change With the Seasons



From: www.indiana.edu/~clp/documents/volunteer_manual/2011_Expanded_Volunteer_Handbook.pdf

Lake Stratification



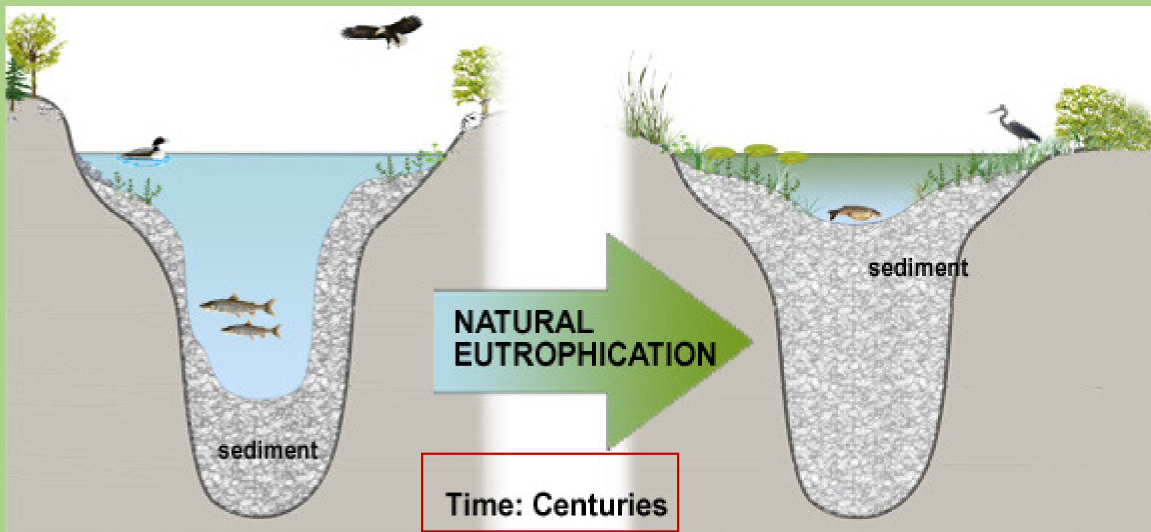
warmer water
zone of
productivity

cooler water
zone of
decomposition

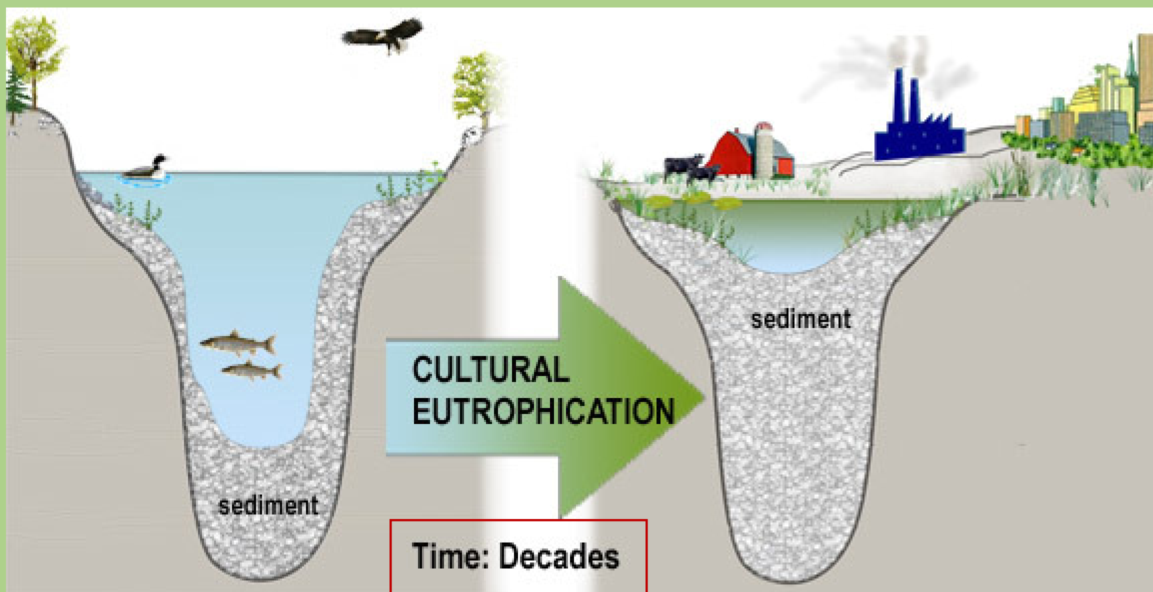
Lake Stresses

- Cultural eutrophication (nutrients)
- Physical
- Acidification
- Toxic contamination
- Exotic species

Natural Versus Cultural Eutrophication



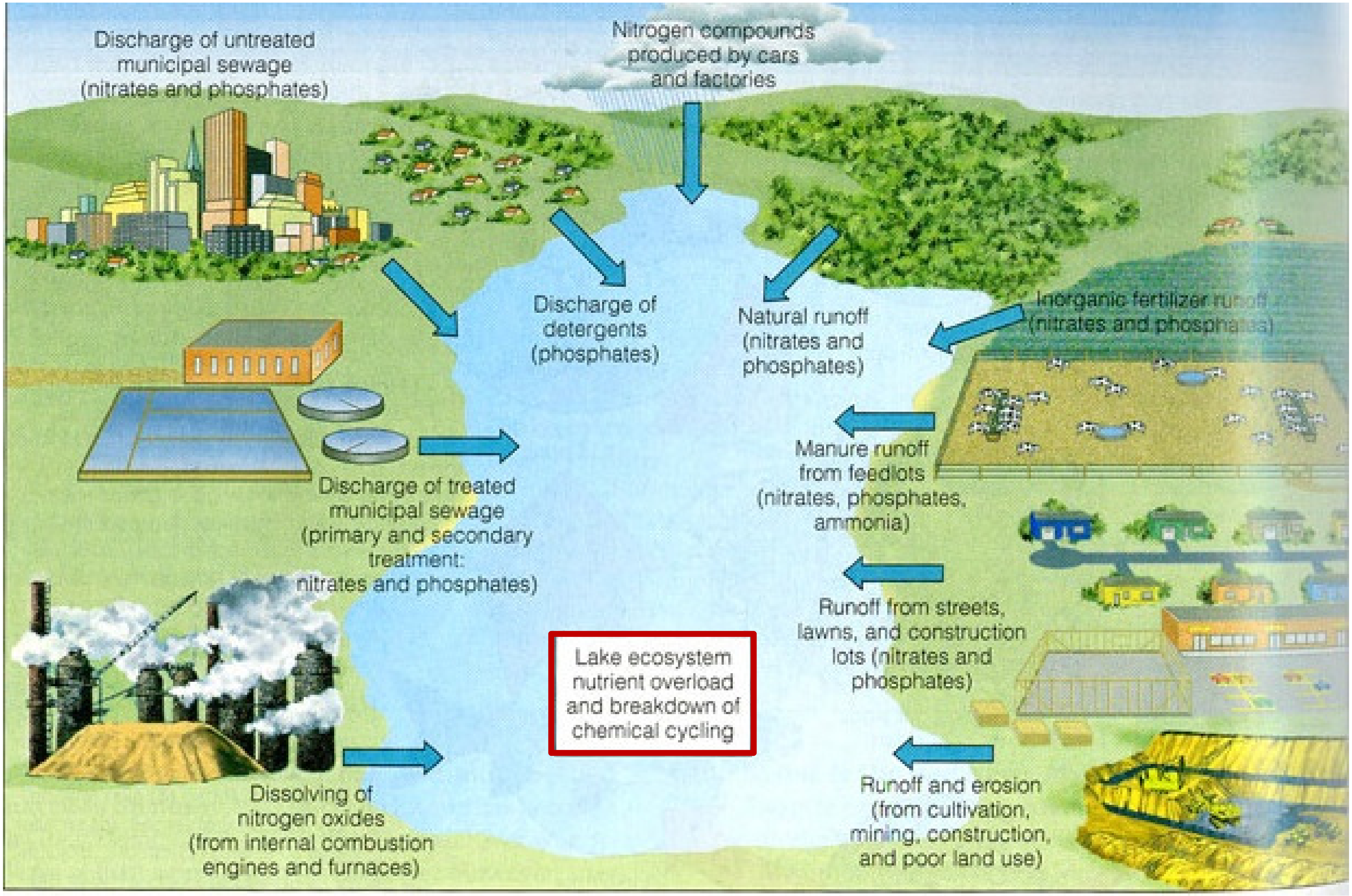
Fill with sediments due to natural erosion processes



Natural aging process accelerated due to human activities

From http://sevenhillslake.com/technical.html

Sources of Cultural Eutrophication



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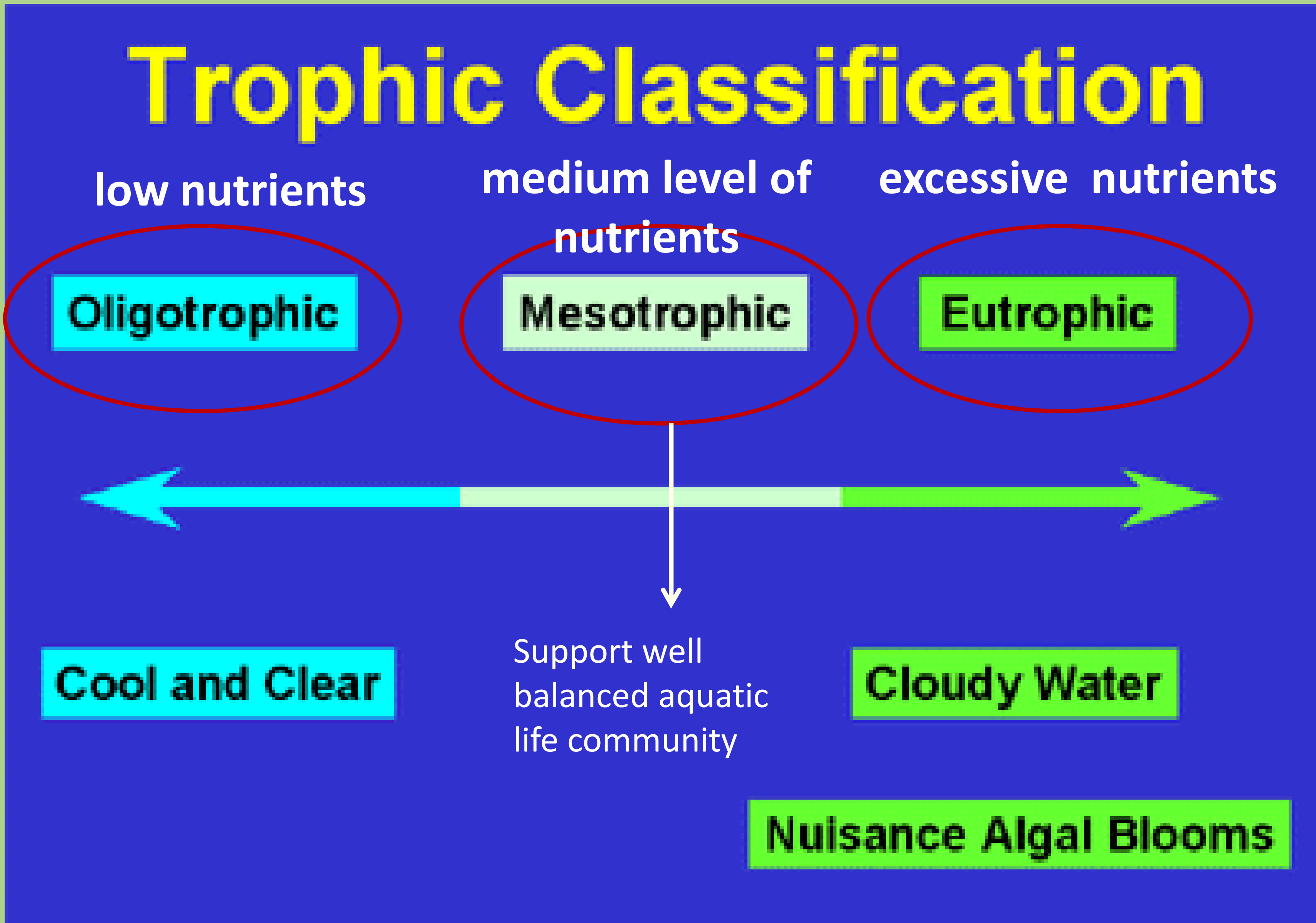
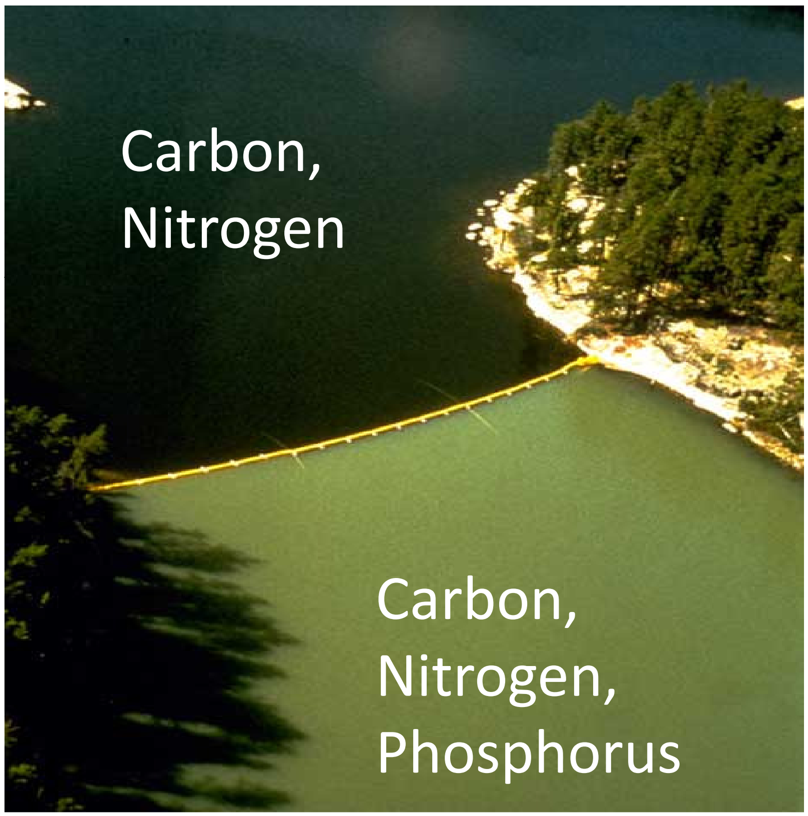


From http://sevenhillslake.com/technical.html

What is Phosphorus?

- Natural element found in soil and in lake sediments
- Fertilizers, detergents, manure, and sewage contain concentrated phosphorus that can be carried into lakes
- Limiting nutrient in freshwaters
  - Lack of availability reduces rate of growth

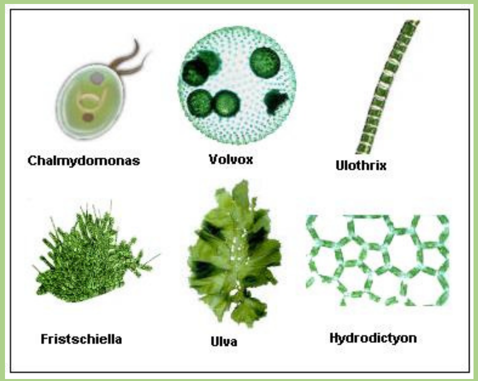
Phosphorous Addition and Eutrophication: An Experimental Study



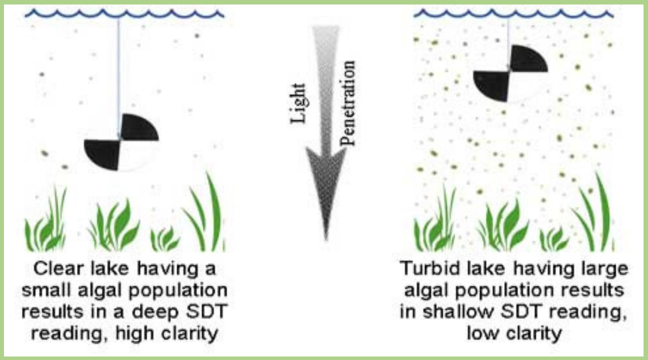
From http://sevenhillslake.com/technical.html

Important Measures of Eutrophication in Lakes

- **Total Phosphorus (TP):** measure of both inorganic and organic forms of phosphorus
  - Most limiting nutrient to plant growth in fresh water
- **Chlorophyll *a* (chl *a*):** most dominant green pigment in algae and plants that allows them to photosynthesize
  - Considered to be a reasonable estimate of algal concentrations
- **Secchi Disk Transparency:** the depth to which the black and white Secchi disk can be seen in the lake water



www.tutorvista.com/content/biology/biology-iii/kingdoms-living-world/algae.php



http://www.mainevlmp.org/wp/?page_id=132

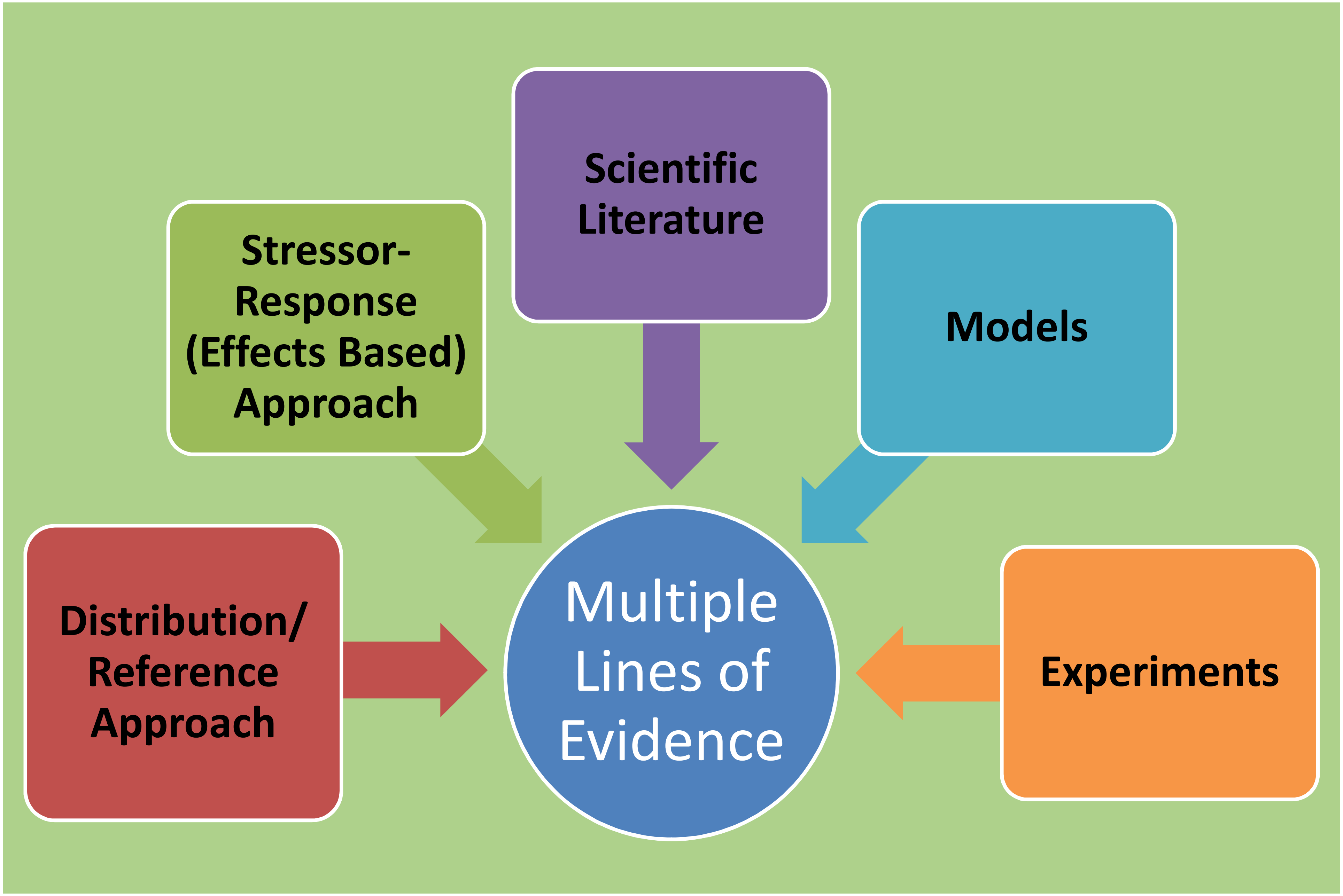
How Are Indiana Lakes Monitored?

- Through the Clean Lakes Program (CLP, Indiana University, SPEA)
  - Public lakes and reservoirs (80/year)
  - Sampling is in July and August
    - Corresponds to thermal stratification
- Water samples collected from three feet below surface and from three feet above bottom
- One site on each lake, usually over deepest part

Parameters Measured by the CLP

- Phosphorus
- Nitrogen
- Secchi Disk
- Temperature
- Light transmission
- Plankton
- Chl *a*
- Dissolved Oxygen (DO)

Approaches for Developing Nutrient Criteria



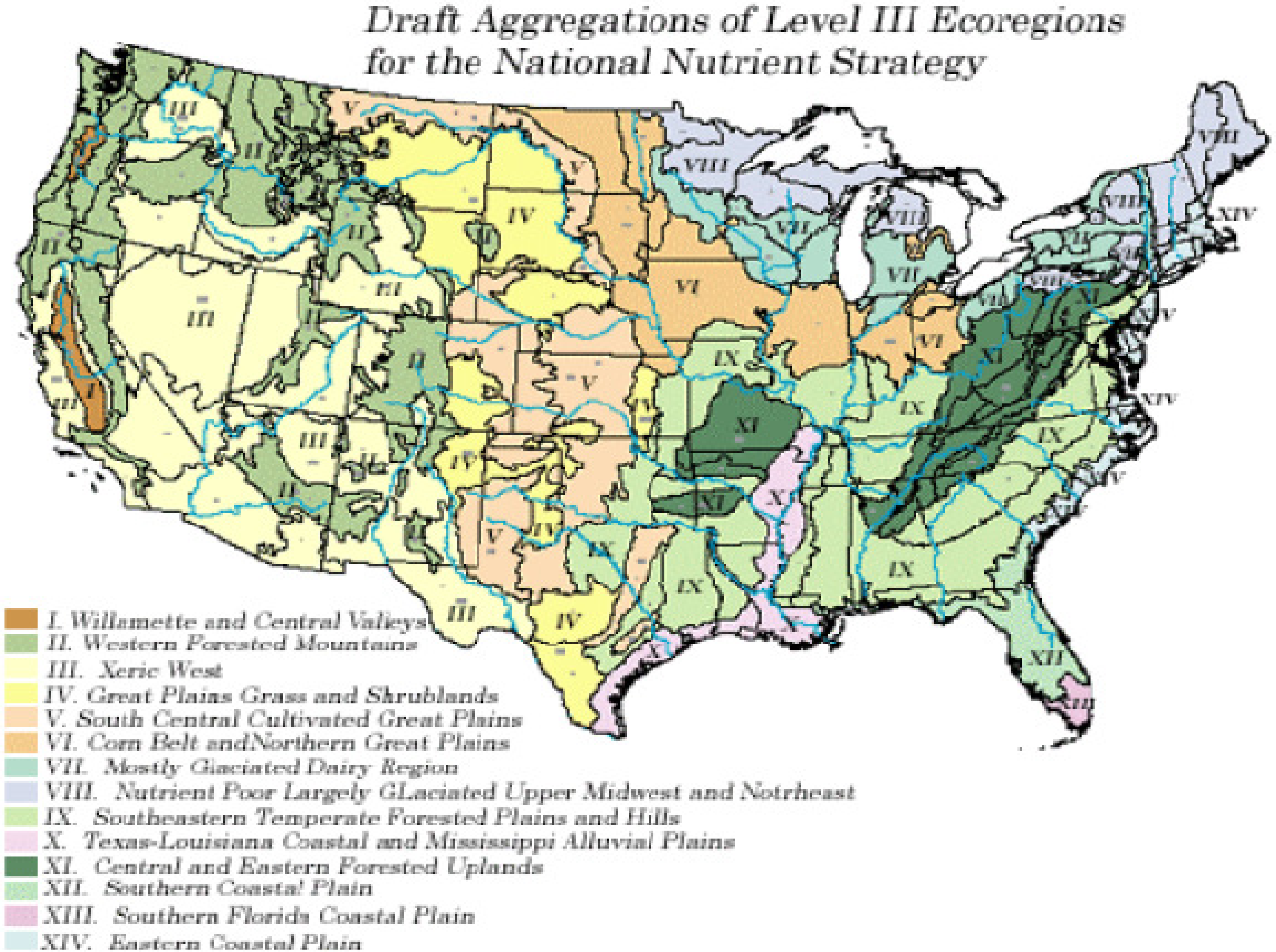
USEPA's National Nutrient Strategy for Developing Criteria

- Reflects ecoregional differences
- Is specific for waterbody type:

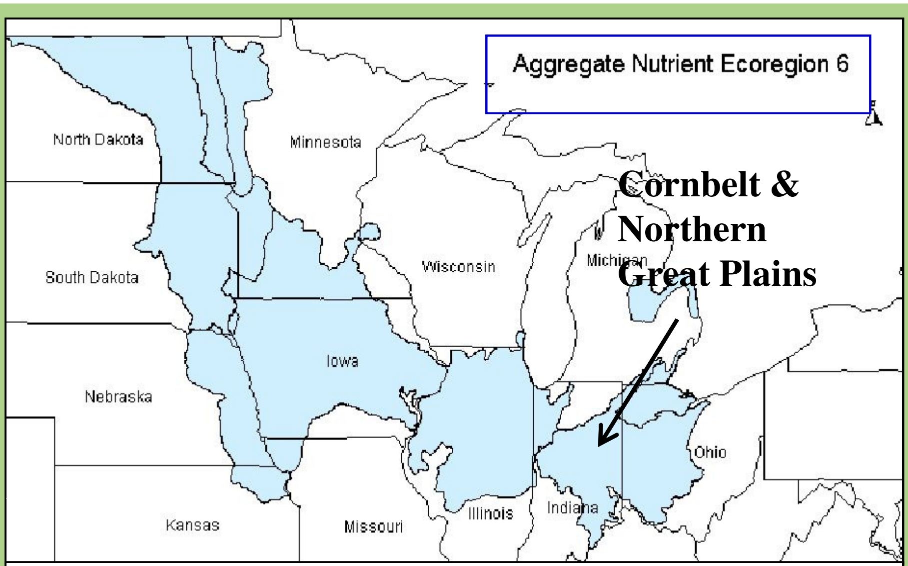
Rivers & Streams	Lakes & Reservoirs
Estuaries & Coastal	Wetlands

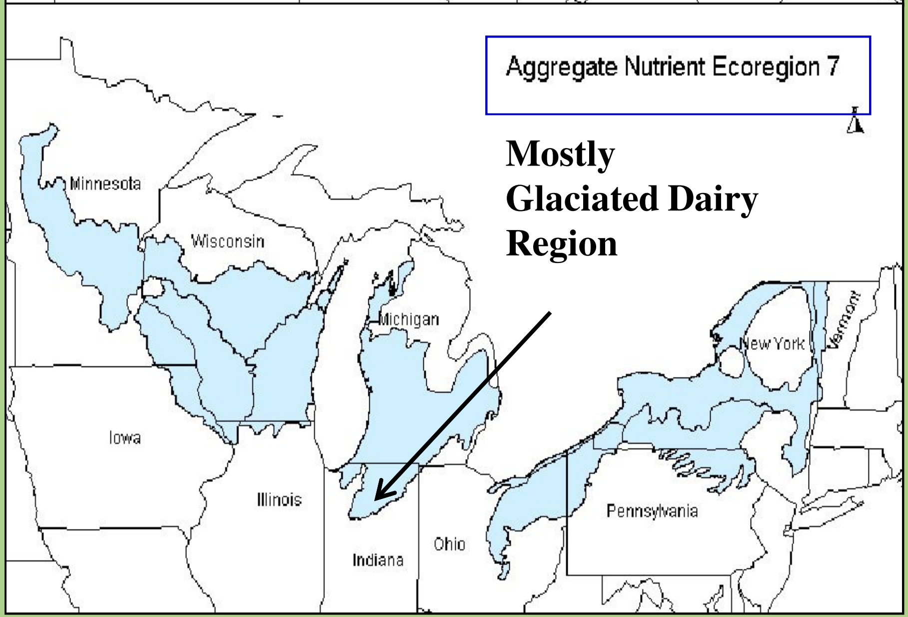
- Includes:

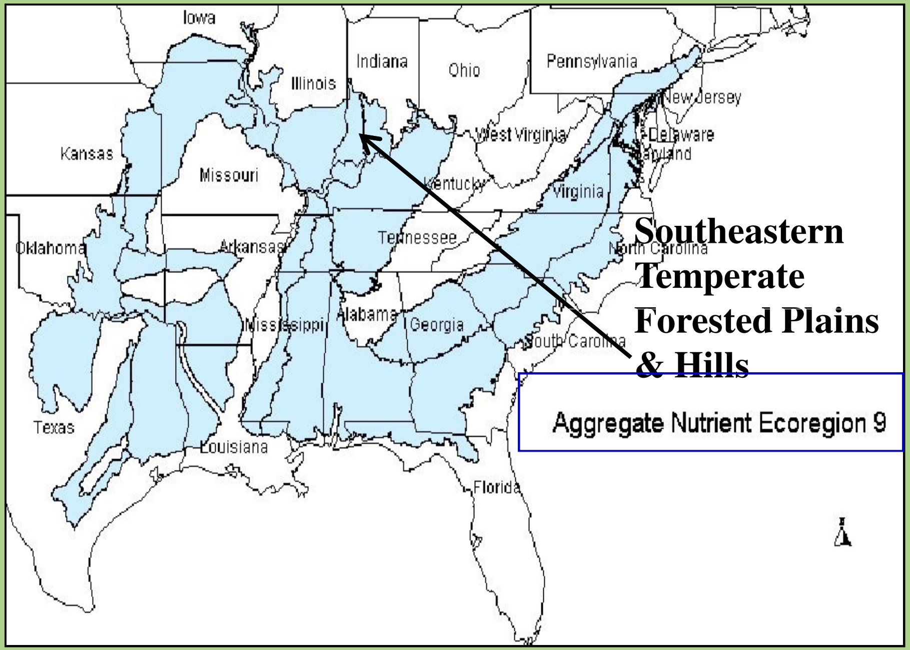
Total Nitrogen	Chlorophyll *a*
Total Phosphorus	Turbidity
(causal variables)	**(early response variables)**


Draft Aggregations of Level III Ecoregions
for the National Nutrient Strategy
I. Willamette and Central Valleys
II. Western Forested Mountains
III. Xeric West
IV. Great Plains Grass and Shrublands
V. South Central Cultivated Great Plains
VI. Corn Belt andNorthern Great Plains
VII. Mostly Glaciated Dairy Region
VIII. Nutrient Poor Largely GLaciated Upper Midwest and Notrheast
IX. Southeastern Temperate Forested Plains and Hills
X. Texas-Louisiana Coastal and Mississippi Alluvial Plains
XI. Central and Eastern Forested Uplands
XII. Southern Coastal Plain
XIII. Southern Florida Coastal Plain
XIV. Eastern Coastal Plain

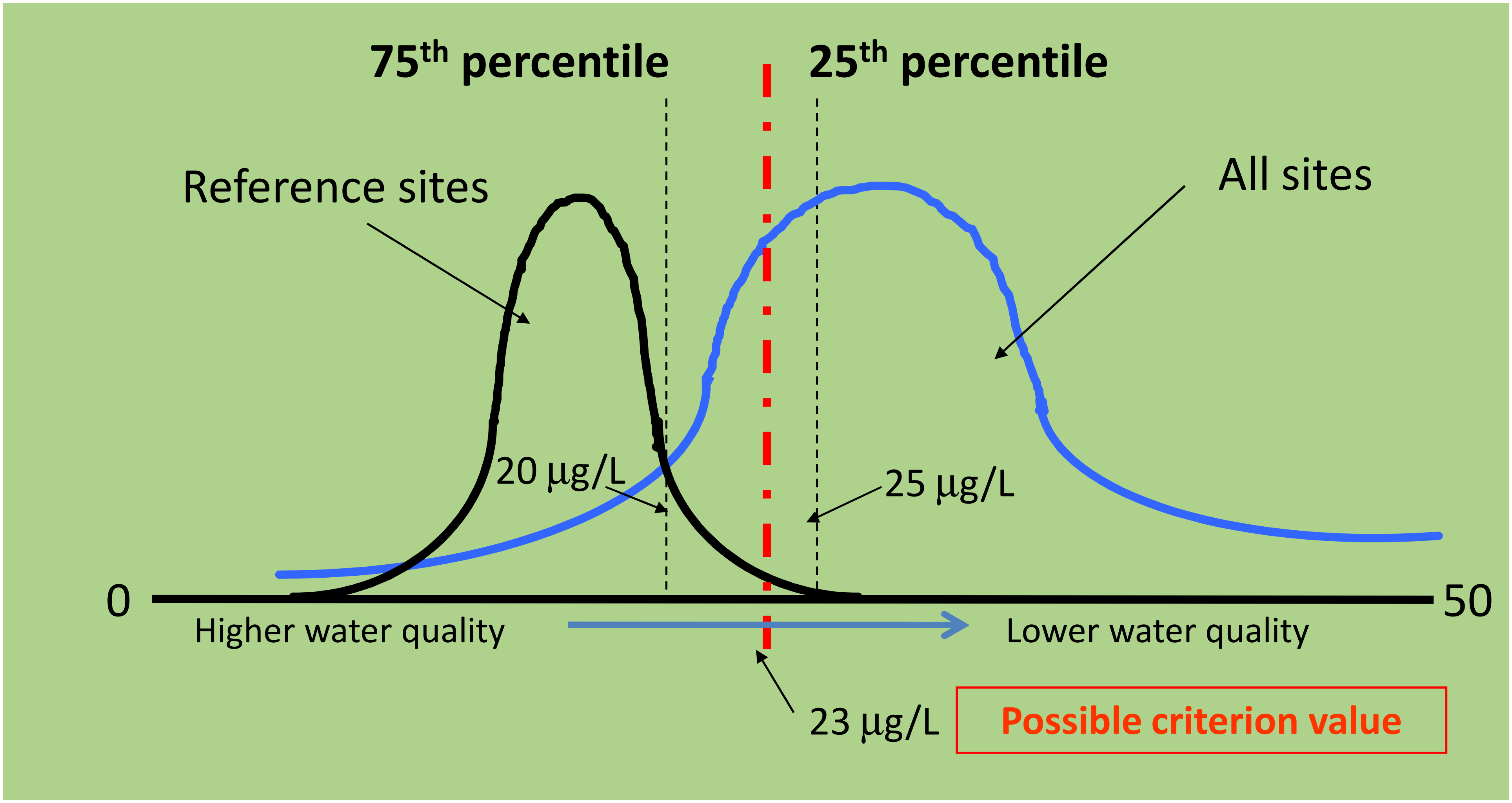
Indiana is Composed of Aggregate Nutrient Ecoregions VI, VII, IX







Distribution/Reference Approach (USEPA Approach)



EPA's Recommended Criteria for Aggregate Ecoregions in Indiana

Aggregate Ecoregion	Level III Ecoregions	TP (μg/L)	Chl *a* (μg/L)	Secchi depth (m)
VI	54, 55, 57	38	9	1.3
VII	56	15	3	3.3
IX	71, 72	20	5	1.5

Scientific Literature

- **Established thresholds**
- **Known effects levels**

Comparing effects of nutrients on algal biomass in streams in two regions with different disturbance regimes and with applications for developing nutrient criteria

R. Jan Stevenson[1,*], Steven T. Rier[2], Catherine M. Riseng[3], Richard E. Schultz[4] & Michael J. Wiley[3]
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DEVELOPING NUTRIENT TARGETS TO CONTROL BENTHIC CHLOROPHYLL LEVELS IN STREAMS: A CASE STUDY OF THE CLARK FORK RIVER

W. K. DODDS[1]*, V. H. SMITH[2] and B. ZANDER[3]
[1]Division of Biology, Kansas State University, Manhattan, KS 66506, U.S.A., [2]Environmental Studies Program and Department of Systematics and Ecology, University of Kansas, Lawrence, KS 66045, U.S.A., [3]United States Environmental Protection Agency Region 8, Suite 500, 999 18th St. Denver, CO 80202, U.S.A.

SUGGESTED CLASSIFICATION OF STREAM TROPHIC STATE: DISTRIBUTIONS OF TEMPERATE STREAM TYPES BY CHLOROPHYLL, TOTAL NITROGEN, AND PHOSPHORUS

WALTER K. DODDS[1]*, JOHN R. JONES[2] and EUGENE B. WELCH[3]
[1]Division of Biology, Kansas State University, Manhattan, KS 66506, U.S.A., [2]School of Natural Resources, 112 Stephens Hall, University of Missouri, Columbia, MO 65211, U.S.A. and [3]Department of Civil Engineering, P.O. Box 352700, University of Washington, Seattle, WA 98195, U.S.A.

Limnol. Oceanogr., 53(2), 2008, 773–787

A framework for developing ecosystem-specific nutrient criteria: Integrating biological thresholds with predictive modeling

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Models

- Link changes in nutrient concentrations to impacts on water quality

Stream Water Quality Model (QUAL2K)

QUAL2K (or Q2K) is a river and stream water quality model that is intended to represent a modernized version of the QUAL2E (or Q2E) model (Brown and Barnwell 1987).

- Sediment-water dissolved oxyge rather than bein nutrient fluxes ticulate organic and the concen waters.
- Bottom algae. bottom algae.

Regional interpretation of water-quality monitoring data

Richard A. Smith, Gregory E. Schwarz, and Richard B. Alexander
U.S. Geological Survey, Reston, Virginia

Abstract. We describe a method for using spatially referenced regressions of contaminant transport on watershed attributes (SPARROW) in regional water-quality assessment. The method is designed to reduce the problems of data interpretation caused by sparse sampling, network bias, and basin heterogeneity. The regression equation relates measured transport rates in streams to spatially referenced descriptors of pollution sources and land-surface and stream-channel characteristics. Regression models of total phosphorus (TP) and total nitrogen (TN) transport are constructed for a region defined as

Controlled Experiments

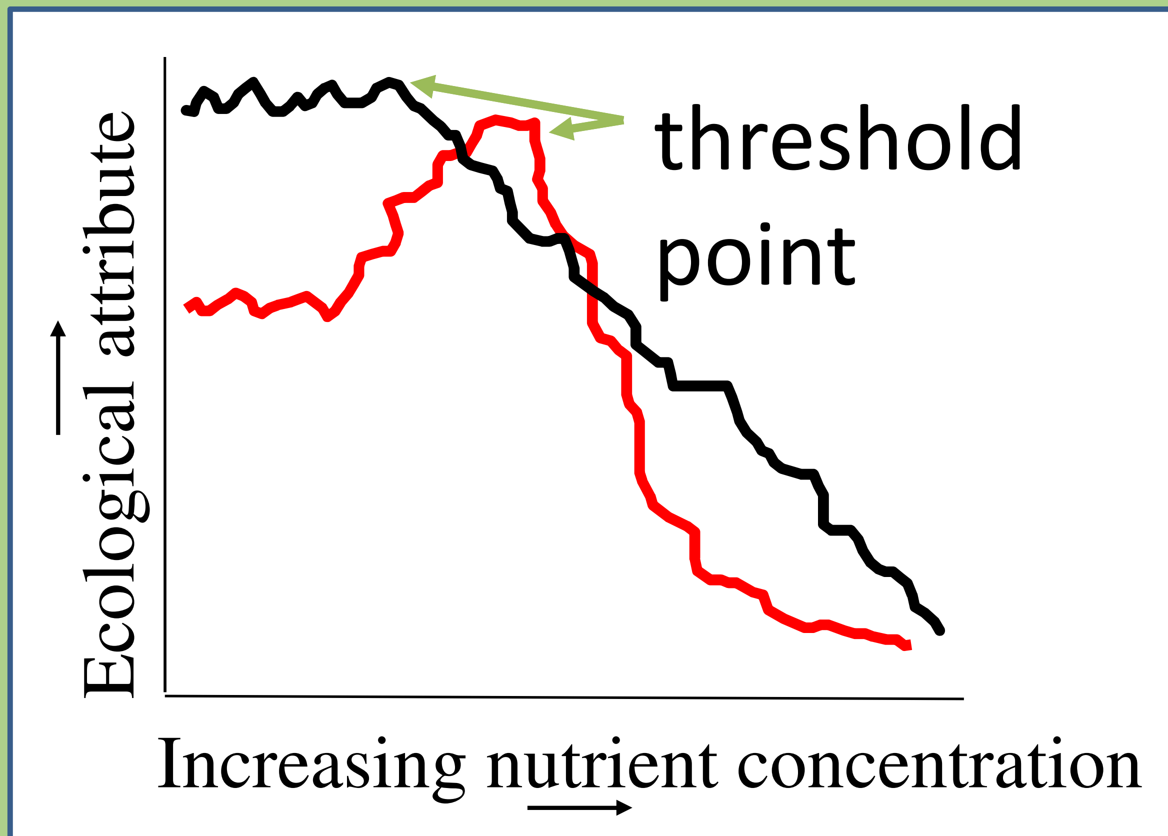
Examples:

- Estimating the effects of excess nutrients on stream invertebrates from observational data
- Long-term nutrient enrichment decouples predator and prey production
- Periphyton removal related to phosphorus and grazer biomass level

→ **Reasonably consistent responses of biotic communities to nutrients**

Stressor-Response Approach

- Estimating relationship between nutrient concentrations and biological response measures



A Five Step Process for Using Stressor-Response Relationships to Derive Nutrient Criteria

Step 1 - Selecting and Evaluating Data

↓

Step 2 – Assessing strength of cause-effect relationship

↓

Step 3 – Analyzing Data

↓

Step 4 – Evaluating response relationship

↓

Step 5 – Evaluating candidate criteria

Selecting Stressor and Response Variables

Stressors – Measure Nutrient Enrichment

Responses – Linked to protection of designated uses and respond to nutrients

Assess Cause-Effect Relationship

Use/develop conceptual models

Consult existing literature

Use modeling

Determine if thresholds exist

Evaluate Candidate Criteria

Evaluate effectiveness of candidate criteria

Weigh uncertainty

Modified from Empirical Approaches for Nutrient Criteria Derivation, USEPA

Multiple Lines of Evidence

- Generate candidate endpoints
- Can be weighted qualitatively using best professional judgment
- Final criterion is a result of multiple lines

12 µg/L
Distribution

20 µg/L
Literature

22 µg/L

22 µg/L
Stressor-response

30 µg/L
Models

Data Used in Indiana's Analysis

- 1989 -2005 data
  - IDEM's AIMS database (Clean Lakes Program)
  - EPA's nutrient criteria database (STORET)
  - EPA's Natural Eutrophication Study
  - Corps of Engineers' reservoir monitoring program
- Two reasons for using data from these years
  - Phosphate ban and lake discharge law resulted in significant improvement in lakes' water quality from 1970s to 1980s
  - Improvement in trophic scores between the 1970s and 1989

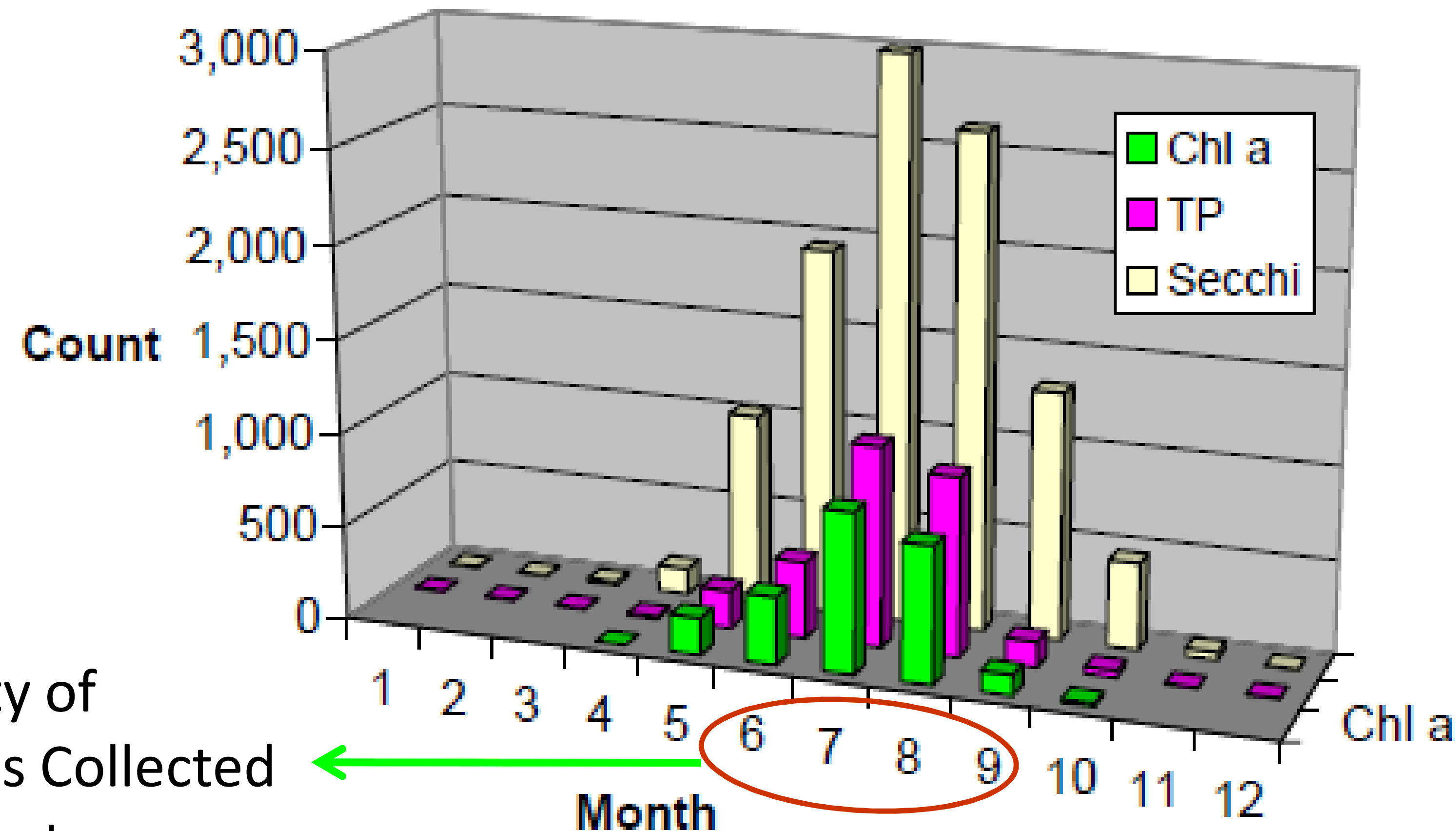
Data (Continued)

- Limno-Tech, Inc.
  - Compilation, QA/QC, and data reduction
- Spatial Data - 3,629 different lentic waterbodies
  - Delineations, land cover (buffer) and watershed area
  - Geology
  - Geomorphology: max and mean depth, area
- Water Quality Data
  - TP, chl *a*, SD, cyanobacteria cell counts, surface and bottom temp, % oxic
  - Summer medians calculated and medians across years then used in data analysis
- "Complete" data for ~520 lentic waters

Number of Indiana Lakes with Spatial or Summer Water Quality Data by Ecoregion

Ecoregion	Any Data		Total Phosphorus and Chlorophyll a		Total Phosphorus and Secchi Depth	
	Number	Percent	Number	Percent	Number	Percent
VI: Corn Belt and Northern Great Plains						
54: Central Corn Belt Plains	**538**	15%	**22**	5%	**21**	4%
55: Eastern Corn Belt Plains	**412**	11%	**44**	9%	**45**	9%
VII: Mostly Glaciated Dairy Region						
56: Southern MI / Northern IN Till Plain	**2,026**	56%	**278**	57%	314	60%
57: Huron/Erie Lake Plain	**0**	0%				
XI: Southeastern Temperate Forested Plains and Hills						
71: Interior Plateau	**282**	8%	**38**	8%	**38**	7%
72: Interior River Lowland	**371**	10%	**104**	21%	**104**	20%
Total	**3,629**	**100%**	**486**	**100%**	**522**	**100%**

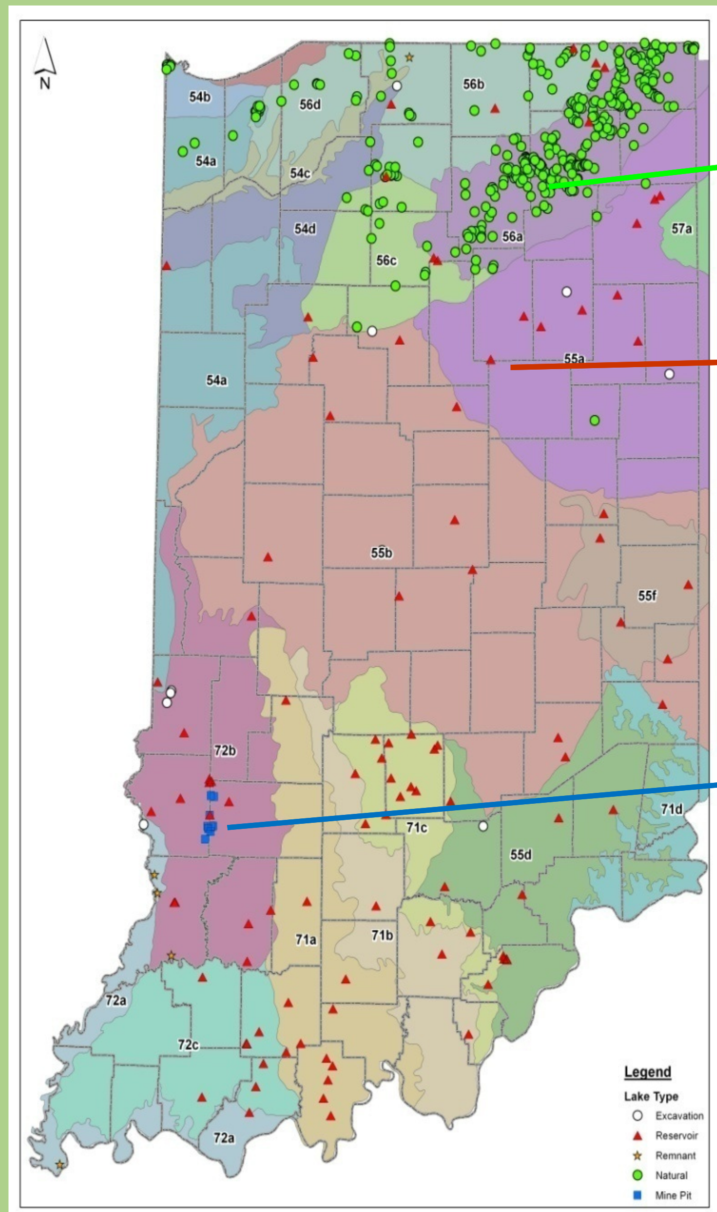
Distribution of Samples by Month



Majority of Samples Collected June-Sept.

Limno Tech, 2007

Indiana Lakes Selected for Analysis



Natural Lakes (320)

Reservoirs (110)

Mine Pits (70)

Others (20)

Limno-Tech, 2007

Data Analysis

- Should/could the lakes be further classified?
- Frequency Distribution Analysis
- Examination of Stressor-Response relationship

Classification of Lakes

- Preliminary classification investigation
  - Multivariate analysis and multiple regression
- Principal Component Analysis (PCA)
  - Data clustering technique
  - Used to explore differences among lakes by type and ecoregion
  - Resulted in lakes being classified into 3 types (natural, reservoirs, mine pits)
- These analyses suggested sufficient differences among lake types to warrant different criteria
  - Less variability in factors when lake types clustered together

Limno Tech, 2007

US EPA's Recommended Values Compared to Values Generated From Indiana Ecoregional Data Using Frequency Distribution Approach

Ecoregion	TP (µg/L)	Chl *a* (µg/L)	SD (m)
VI – IN	33	2	2
VI – EPA	38	9	1.3
VII – IN	23	2	2.7
VII – EPA	15	3	3.3
IX - IN	18	1	3.9
IX - EPA	20	5	1.5

Limno Tech, Inc.

Results of Frequency Distribution Analysis

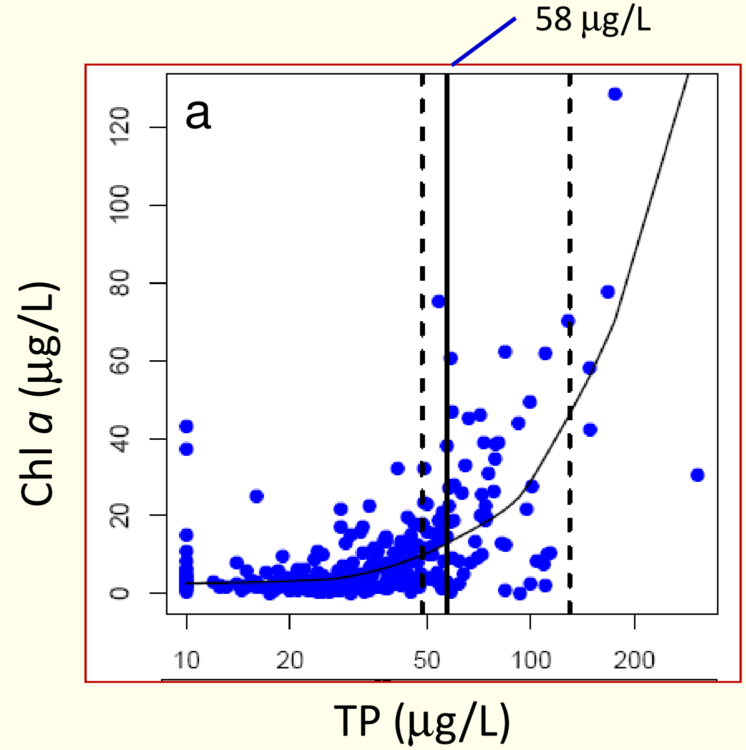
	Mean	Std Dev	25^{th}	75^{th}	N
All Lakes					
TP (µg/L)	52.8	64.5	**22.0**	58.0	524
Chl *a* (µg/L)	18.2	29.9	**1.7**	17.7	524
Secchi depth(m)	2.5	6.3	1.1	**2.9**	524
Natural Lakes					
TP(µg/L)	45.6	39.1	**23.0**	54.0	321
Chl *a*(µg/L)	21.2	32.2	**2.4**	19.6	321
Secchi depth (m)	2.6	7.9	1.2	**2.7**	321
Natural Lakes - Reference Only					
TP (µg/L)	45.2	36.3	22.5	**55.0**	58
Chl *a* (µg/L)	9.0	12.6	1.8	**13.4**	51
Secchi depth (m)	2.1	1.0	**1.4**	2.9	58
Reservoirs					
TP (µg/L)	80.5	102.5	**28.0**	94.0	113
Chl *a* (µg/L)	18.4	28.0	**1.7**	26.7	113
Secchi depth (m)	1.7	1.5	0.7	**2.5**	113
Mine Pits					
TP (µg/L)	25.9	26.0	**12.0**	29.0	73
Chl *a* (µg/L)	2.4	3.7	**0.6**	1.9	73
Secchi depth (m)	3.5	1.9	1.7	**4.5**	73
Other					
TP (µg/L)	120.4	119.6	**30.5**	217.0	17
Chl *a* (µg/L)	27.6	38.9	**4.2**	36.3	17
Secchi depth (m)	1.3	1.1	0.3	**2.0**	17

Tetra Tech, Inc.

Stressor-Response Analysis

- Change-point
  - Method for identifying thresholds in relationships between two variables
  - Identifies principal change point in relationship between 2 variables
  - Example question: is there a threshold in the response of chl *a* to gradients in total phosphorus?

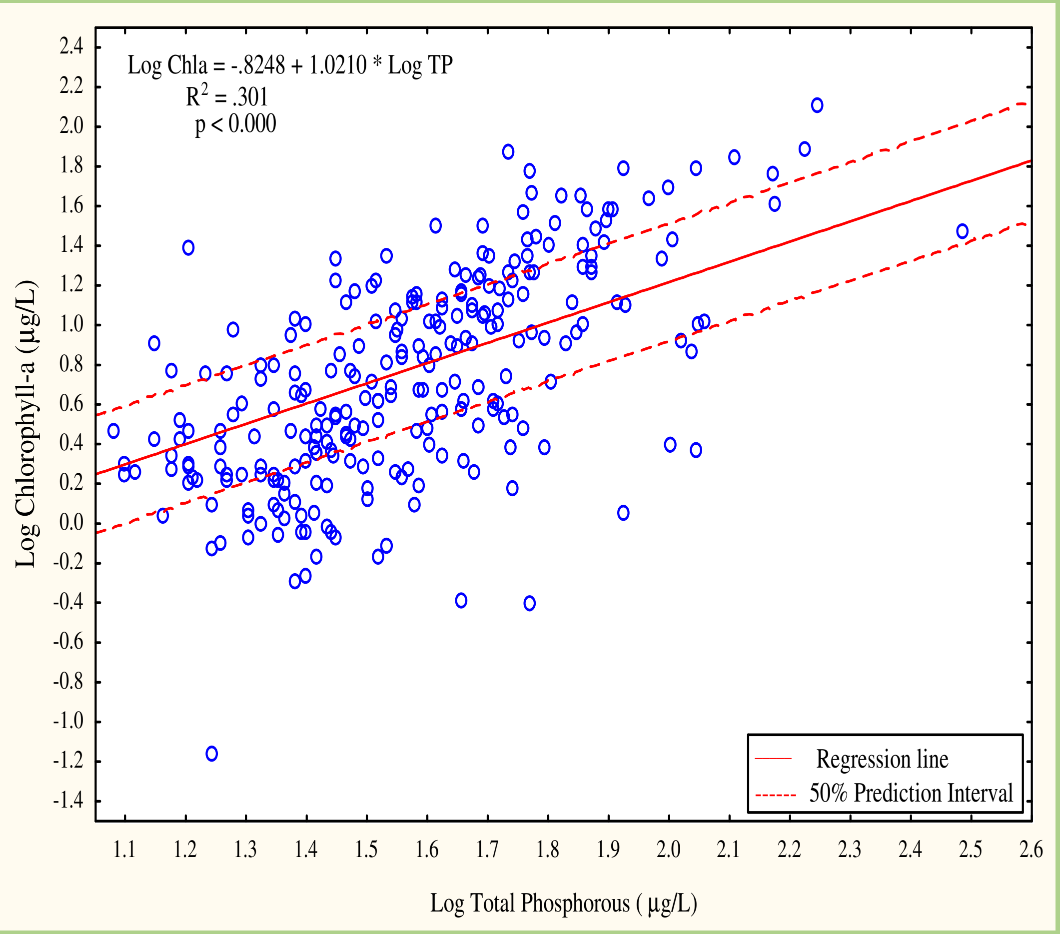
Summer Median Chl *a* vs. TP in Natural Lakes



Tetra Tech, Inc.

Stressor-Response Analysis

- Regression
  - Technique that treats one variable as a function of another
  - Example question: can total phosphorus concentrations be used to determine the chl *a* content in a lake?



Trophic State Boundaries for Chlorophyll and Secchi Depth used in Regression Analyses

- Expected trophic status of lakes used to derive proposed chl *a* concentrations protective of:
  - Natural balanced populations of aquatic communities, and
  - Recreational uses

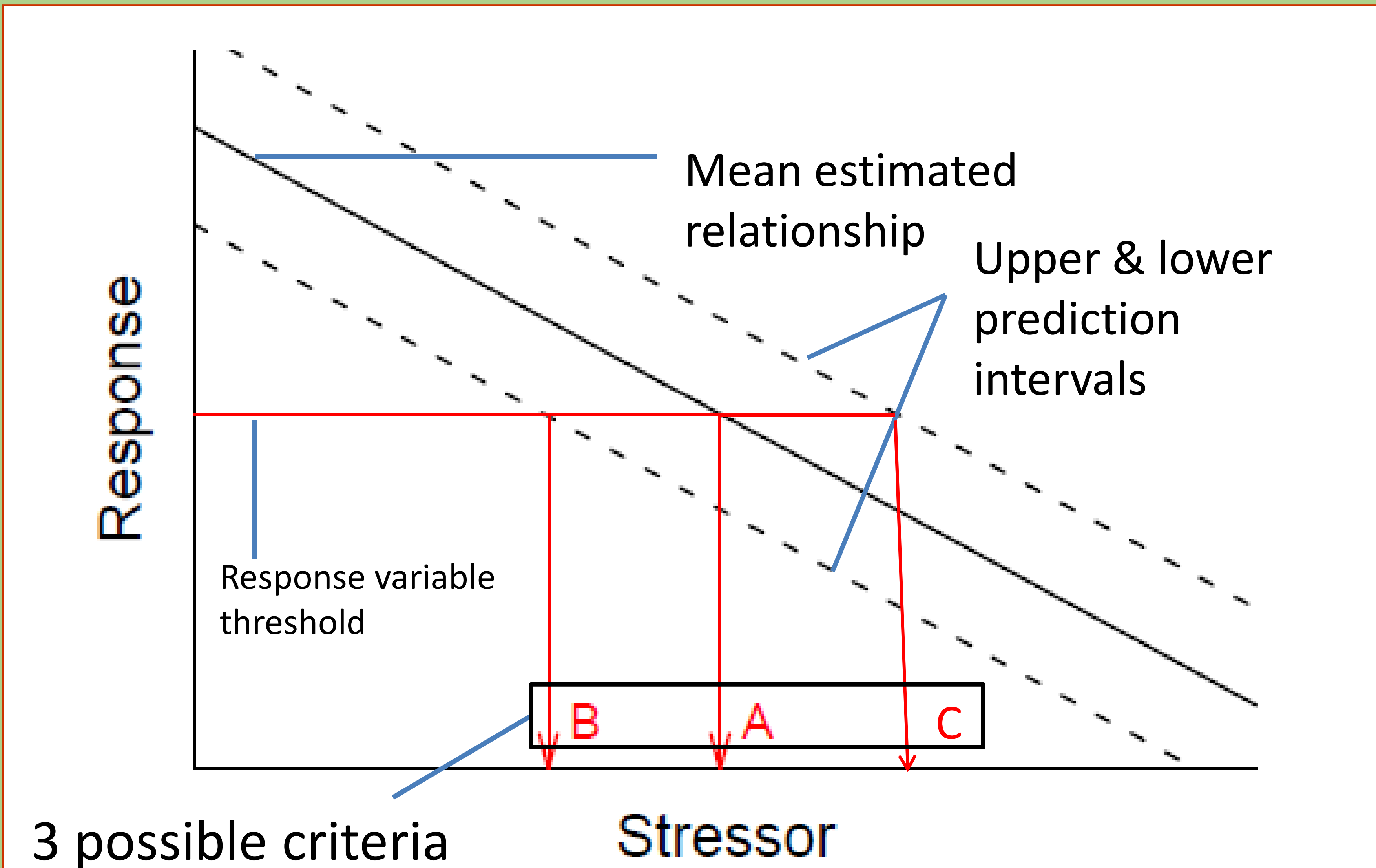
Trophic State	Chlorophyll (µg/L)	Secchi Depth (m)
Oligotrophic	<2.5	>6
Mesotrophic	2.5-8.0	3-6
Eutrophic	8.0-25	3-1.5

Source: Organization for Economic Cooperation and Development (OECD). 1982. Eutrophication of Waters. Monitoring Assessment and Control. Final Report. OECD Cooperative Programme on Monitoring of Inland Waters (Eutrophication Control). OECD, Paris.

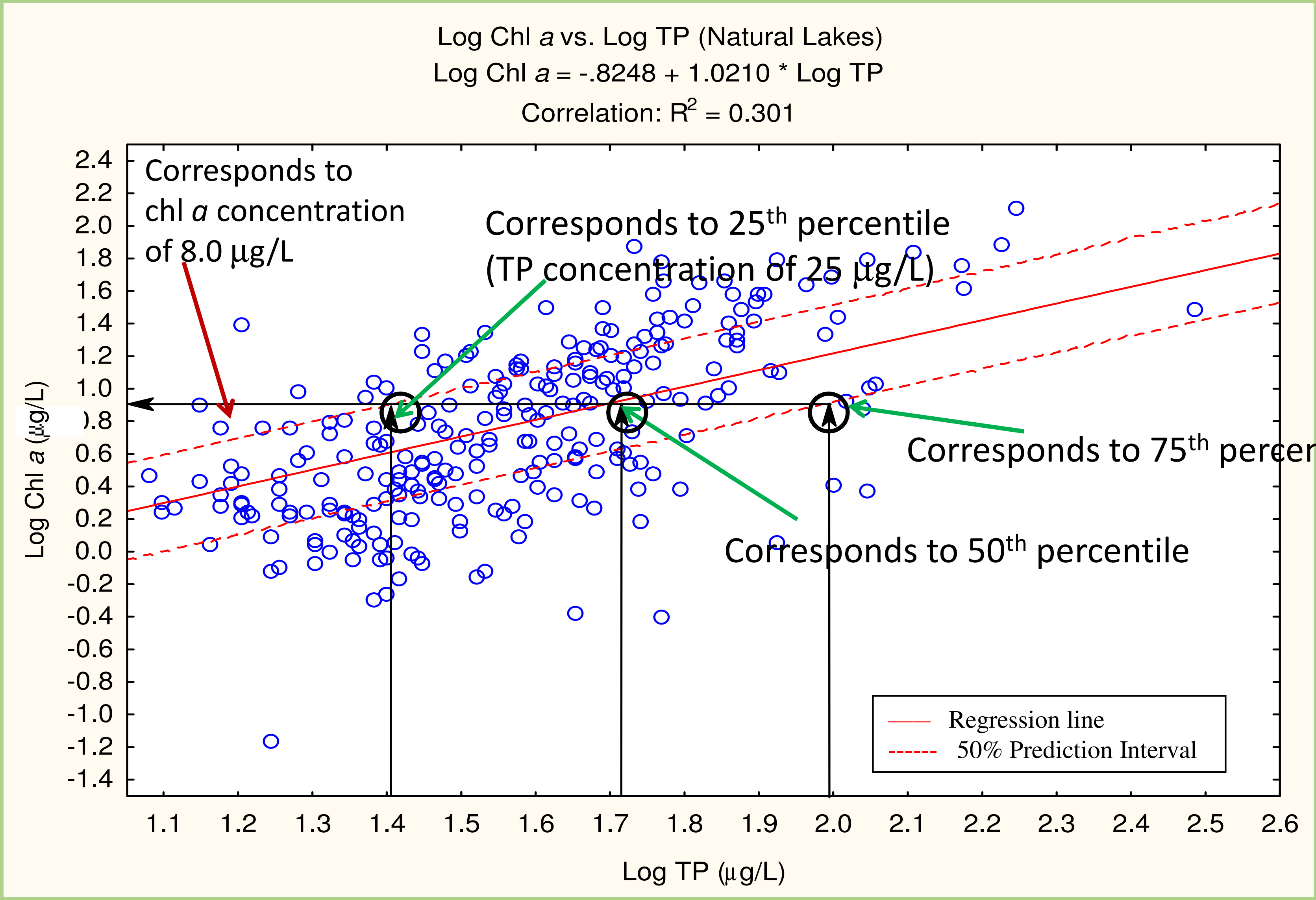
Basis of Numeric Criteria Development for Indiana Lakes

- Based on stressor-response approach
- Summer (June-Sept.) concentrations of chl *a* and TP measurements are the primary indicators of balance of flora and fauna

Simple Linear Regression



Translating Response Threshold to Candidate Criterion: Natural Lakes



What Does This Mean?

- Different prediction intervals can be used to define criteria with different degrees of “protectiveness.”
- Example: if proposed criterion of 25 µg/L is based on 25th percentile prediction interval, there is less than 25% chance of exceeding chl *a* of 8 µg/L.

Summary of Results from All Analyses

	TP (μg/L)	Chl *a* (μg/L)
Distribution Based		
Natural	23	2.4
Reservoir	28	1.7
Stressor-Response (Change Point)		
Natural	47	
Reservoir	56	

Summary of Results

Stressor-Response (Regression)	Chl *a* (μg/L)	TP (μg/L) 25th percentile	TP (μg/L) 50th percentile	TP (μg/L) 75th percentile	Correlation
Natural (n =284)	8	25	49	98	$R^2 = 0.301$
Reservoir (n = 112)	8	35	69	126	$R^2 = 0.437$

Supporting Lines of Evidence for Proposed TP Criterion

23 µg/L

Distribution

31 µg/L

Conditional probability

$\boxed{\textbf{25 µg/L}}$

Regression analysis

20 µg/L

Unpublished scientific data

47 µg/L

Change point

Natural Lakes

Supporting Lines of Evidence for Proposed TP Criterion

28 μg/L

Distribution

43 μg/L

Conditional probability

35 μg/L

Regression analysis

20 μg/L

Unpublished scientific data

56 μg/L

Change point

Reservoirs

Proposed Criteria

A	B	C
Lake Type	**Chl *a* (µg/L)***	**TP (µg/L)***
Natural	**8**	**25** (25-98)
Reservoir	**8**	**35** (35-126)

* Concentration values are based on an arithmetic mean during the period June-September.

* Expressed as an annual mean not to be surpassed once every three years.

Modified Criteria

- Baseline criteria for TP apply unless IDEM establishes "modified criteria"
  - To be eligible, must meet chl *a* magnitude for at least the 3 immediately preceding years, and must meet data requirements
    - Sufficient ambient monitoring data for chl *a* and TP for at least the three immediately preceding years
    - At least four measurements/year for each parameter with one sample each in the months of June-September
  - Must be within range shown in brackets (column C)

Lakes Eutrophication Criteria for Other EPA Region V States

State	Criteria	Adoption	Approach
IL	TP- 0.50 µg/L	1979	EPA's Red Book
MI	TP (modeled criterion)	TBD	Predictive Modeling & Lowess Curves
OH	TP: 14-38 µg/L TN: 450-1225 µg/L Chl *a*: 6-14 µg/L Secchi depth: 1.19-2.6 m	2012	Frequency Distribution Approach
WI	TP: 15-40 µg/L	2010	Limiting nuisance algae
MN	TP: 12-90 µg/L Chl *a*: 3-30 µg/L Secchi depth: 0.7- 4.8 m	2008	Frequency Distribution Approach

Questions?

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